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BEST MANUFACTURING PRACTICES

REPORT OF SURVEY CONDUCTED AT

TEXAS INSTRUMENTS DEFENSE SYSTEMS AND ELECTRONICS GROUP LEWISVILLE, TEXAS

MAY 1986

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The purpose of the Best Manufacturing Practices (BMP) survey conducted at this facility was to identify their best practices, review manufacturing problems, and document the results. The intent is to extend the use of progressive management techniques as well as high technology equipment and processes throughout the U.S. industrial base. The actual exchange of detailed data will be between contractors at their discretion. A company point of contact is listed in the report.

The intent of the BMP program is to use this documentation as the initial step in a voluntary technology sharing process among the industry.

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REPORT OF SURVEY

CONDUCTED AT

TEXAS INSTRUMENTS

DEFENSE SYSTEMS & ELECTRONICS GROUP

LEWISVILLE, TEXAS

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I. INTRODUCTION

A. Scope

The purpose of the Best Manufacturing Practices (BMP) Review conducted at Texas Instruments (TI) was to identify best practices, review manufacturing problems and document the results. The intent is to extend the use of high technology equipment and processes throughout industry. The ultimate goal is to strengthen the U.S. industrial base, solve manufacturing problems, improve quality and reliability, and reduce the cost of defense systems.

To accomplish this, a team of Navy engineers and managers reviewed TI's Defense Systems and Electronics Group (DS&EG) to identify the most advanced manufacturing processes and techniques used in that facility. Manufacturing problems that had the potential of being industry wide problems were also reviewed and documented for further investigation in future BMP reviews. Demonstrated industry wide problems will be submitted to the Navy's Electronic Manufacturing Productivity Facility for investigation of alternatives to resolve the problems.

The review was conducted at the DS&EG in Lewisville, Texas with visits to TI's Trinity Mills and Sherman, Texas plants on 6-9 May 1986 by a team of Navy personnel identified on page 2 of this report. DS&EG is primarily engaged in the development and production of the HARM Missile System.

Based on the results of BMP reviews, a baseline is being established from which a data base will be developed to track best practices and manufacturing problems. The information gathered will be available for dissemination through an easily accessible central computer. The actual exchange of detailed data will be between contractors at their discretion.

The results of this review should not be used to rate TI against other defense electronics contractors. A contractor's willingness to participate in the BMP program and the results of a survey have no bearing on one contractor's performance over another. The documentation in this report and other BMP reports is not intended to be all inclusive of a contractor's best practices or problems. Only selected non-proprietary practices are reviewed and documented by the BMP survey team.

B. Review Process

This review was performed under the general survey plan guidelines established by the Department of the Navy. The review concentrated on three major functional areas: management, design engineering and manufacturing. The team observed practices and equipment used in these areas. TI gave an overview briefing on each of the areas identified as best practices and potential industry wide problems. These practices and problems and other areas of interest identified were followed up by on the factory floor reviews and individual meetings between Navy team members and TI personnel.

The Navy team documented potential best practices which will be investigated and compared with the rest of industry. Manufacturing problems encountered by TI DS&EG were also discussed and are documented in this report.

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II. SUMMARY

The Best Manufacturing Practices Survey Team evaluated management, design and manufacturing functions. Areas reviewed included the contractor's management policies and procedures, transition planning, design and production engineering, material procurement, receiving inspection, facilities, equipment, test equipment, quality assurance, material handling, inventory control, manufacturing technology and vendor selection and control.

The format for the survey consisted of a general overview of the functional areas highlighting best practices and problem areas and a plant tour on the first day. The next two days were spent reviewing in detail those areas identified. Time was spent on the factory floor reviewing practices, processes and equipment. In-depth discussions were also conducted with TI personnel to document some of the practices and problems identified. Several of the Navy team members visited the Trinity Mills and Sherman plants, which are off-site support facilities. These facilities are involved in CAD/CAM enhancements, statistical quality control, robotic manufacturing, computer work order system, and flexible manufacturing systems.

TI DS&EG's main focus appears to be on automation, efficient plant layout and employee involvement. Within these key areas the emphasis is on improving quality, productivity, reliability, yield, and reducing scrap and rework.

Since corporate management made the decision in 1970 to automate, many changes have taken place in the factory. Automation can be seen in material handling and storage, robotics, machining, parts insertion, soldering, inspection and test analysis. Automated inventory control and just-in-time manufacturing have been implemented in several areas. TI has removed the human error factor and instituted complete automation of operations in as many areas as possible.

TI dedicates a lot of effort to manufacturing detail and improving operator processes. This is driven by management's desire to reduce defects and improve the quality and reliability of the product. The Navy team found that this has lead to the development and utilization of many positive practices at TI which have the potential of being best manufacturing practices.

The main manufacturing problems identified by TI were vendor and specification related. Vendor problems appear to be common throughout the electronics industry. Specification tailoring, government non-acceptance of digitized data as "master" drawings, government furnished equipment impact on just-in-time manufacturing, and insufficient training capacity for Navy WS 6536 were also identified as constraints to manufacturing that often result in increased cost and poor quality.

The best manufacturing practices and problems identified at TI DS&EG will be evaluated and reviewed by the Navy team during future BMP surveys. Those practices identified as being among the best in the electronics industry will be documented in a central data base for dissemination throughout the industrial base. The industry wide problems will be investigated by the Navy in an effort to develop alternatives for their resolution.

III. BEST PRACTICES

The practices listed in this section are those identified by the Navy BMP survey team as having the potential of being among the best in the electronics industry. It is premature to say they are the best at this time since this is only the third BMP survey and an industry baseline is still being established.

A practice that is considered to be one of TI's best is the ability to automate many manufacturing processes with a high level of success. Many of those practices are discussed in detail in this section.

A. Management

AUTOMATED MANUFACTURING

Texas Instruments made decisions at the corporate level in the mid to late 1970's to incorporate an automation philosophy into as many facets of its operations as deemed appropriate. The corporate structure set goals and adapted a strategy which employed a high degree of manufacturing automation and computerization.

Computerization is obvious everywhere: on desk tops and incorporated in equipment, including portable and automatic test equipment. Systems include TI PC's, IBM PC's, VAX, Apollo and Daisy. On an average there is one computer for every two employees. TI tries to take the human judgment, human error factors out of the process through automation. There is a continual process of improvements, further automation and tying the complete operations together rather than only having discrete small automated areas.

Various degrees of manufacturing automation are evident in such areas as component insertion, solder mask application, wave soldering, cleaning, assembly inspection, conformal coating, assembly testing, system testing, microwave circuit board fabrication, metal fabrication, and management information systems.

The corporate strategy to automate in an effort to improve quality, reduce costs, maintain schedules, reduce and improve design and manufacturing cycles has been very successful. The real best practice is the dedicated corporate strategy to get the maximum exchange of data by implementing a total factory integrated automation program.

MANUFACTURING PLANNING SYSTEMS

TI is developing its own Manufacturing Planning System (MPS) to provide an interface between various existing material systems. MPS provides the following information to manufacturing: contract information, bill of material (BOM) structure and part data, inventory balances and transaction history, manufacturing build schedule, material plan, and execution status. Some of the 1960 state-of-the-art disjointed systems were replaced before MPS could be initiated. Major systems thrusts included closed-loop manufacturing planning and JIT, systems integration, paperwork reduction, improved data collection, site-level and local computing with factory networking, and management (summary) reporting.

Systems installed to date include BOM update, inventory control/ warehousing, and Material Requirements Planning (MRP) pilot system. Planned are master production scheduling and capacity planning. The major goals of classical MRP are inventory control, priority planning, and capacity planning. MRP features include total product structure explosion to determine requirements, end-of-business visibility of requirements and orders, net change replanning, electronic forward purchase orders, exception/action message reporting, enhanced status information (on-line), line of balance reporting for all made parts, and improved execution systems interfaces. MRP interfaces include BOM, inventory, purchasing, fabrication, and assembly.

SOURCE SELECTION AND MATERIAL CONTROL

There is a growing movement in the electronics industry to reduce the supplier base, increase supplier quality, consolidate volumes, and establish long-term integrated supplier relationships. TI has established a Material Control Organization to support divisional and group objectives in this area. A purchased materials planning manager has been assigned and a proactive team approach is being used.

By consolidating and controlling the number of suppliers, TI has realized increased buying power and developed stronger corporate purchase agreements. Concentrating on fewer suppliers has resulted in better quality, delivery, and the development of strategic relationships. Supplier consolidation has also reduced the cost of paperwork, people, and computers. Many transactions between TI and its suppliers are via computer links.

A key ingredient to the success of this effort has been to insure the suppliers understand the importance of quality, schedule and cost. TI manages this effort with a cohesive team with representation from Manufacturing, Quality, Engineering, and Purchasing.

The overall goal of selection and control is to get the suppliers' attention to quality, increase the suppliers' quality to 100% and reduce incoming faults to zero. A computerized system for tracking quality has been employed. Poor quality suppliers have been dropped and those remaining have been helped to improve their quality, making quality the most important criterion in award decisions.

The supplier rating system is comprehensive, controlled and appears to give a reasonable supplier evaluation. Through these dedicated and firm procurement practices, at the close of 1985, 70% of defective products were being returned to supplier and the "use as is" material has been reduced to 5%. The thrust in supplier management is on commodity consolidation, systems innovation, material teams, and major supplier strategy.

PROCESS DOCUMENTATION

TI has applied configuration control to its shop processes. The processes/procedures have been written up in both detail and brief form to provide TI operators with accurate, easy to use, written procedures from which to work. Currently, there are 47 processes, 12 laboratory procedures, 20 rework procedures, and three repair procedures included in a single book. The process books are color coded by area, serialized, and marked with the applicable revision letter after update. The books are issued to the supervisor, who issues one to each work station, or they are posted on the equipment. Process engineering maintains records of book issue.

There is a process review board which must approve all changes to these procedures in the same manner as for drawings and specifications. The board consists of a chairman, the process engineering manager, a manufacturing manager, and a quality manager. This board ensures that all changes to the procedures are based on data/information which has been properly reviewed and documented.

TI also has an operator training and certification program in place to ensure that only properly qualified operators work on DOD hardware. To become certified for a particular process or technique, an operator receives on-the-job training, attends a quarterly certification training course, and in certain applications, must pass a written examination. The operator must also attend semi-annual recertification classes to ensure that his skills have not deteriorated.

QUALITY INFORMATION SYSTEMS

TI's Quality Information Systems (QIS) is one of the more advanced and comprehensive systems the BMP team has seen in industry, with capability to collect large amounts of inspection and test data. This data provides closed loop control for managing quality by providing sufficient accuracy to detect problems and trends. QIS provides real-time, on-line retrieval of data and is integrated with systems in purchasing, manufacturing and engineering. It replaces

stand alone, fragmented QRA (quality, reliability and assurance) with an integrated data base and modular application system.

TI has developed/implemented QIS to provide an advanced management information system which assimilates and communicates quality indices. They have accomplished major improvements in product quality, reliability, yield, scrap and rework. Management is considering plans to market QIS to other major military contractors.

TOTAL QUALITY CONTROL

The Texas Instruments, Sherman facility has implemented a Total Quality Control (TQC) procedure. The intent of TQC is to make quality the responsibility of the machine operator. This expands the function of quality control into manufacturing while not degrading the function of manufacturing. Under TQC, the operator inspects and the inspector audits. To accomplish/implement TQC, the operator must be trained in order to be qualified to inspect and receive that additional responsibility. The operator and the inspector both truly belong to the same team under this system. Under TQC, the operator has the authority to shut down an entire fabrication line, if he feels it necessary, when a problem is discovered through his efforts.

The TQC system is innovative and through it the operator improves his capability/output while the overall quality and yield of the company is improved. If the operator is informed, trained and responsible for quality, the product will improve.

EFFECTIVENESS TEAMS

The Effectiveness Teams (ET) Program is a quality circles concept which encourages formation of teams in work areas to address problems in those areas. The teams consist of a steering committee, a coordinator/facilitator, a team leader (preferably not from supervision/management), and team members (preferably not more than 12). Each team meets once a week for one hour on company time to work on problems. The meetings are held in conference rooms set aside primarily for the ET meetings. The sessions are informal but must follow a formal seven step problem solving process. The ET learns to work as a team and how to solve problems. TI provides training in ET to supervisors. Management emphasis is placed on quality first, schedule second, and cost last.

ET's were initiated in 1982; there are now 700 teams at 23 sites. TI benefits from the program in various ways, including improving quality and productivity, fostering creativity, creating a more personalized work environment, increasing communication at all levels, and promoting cost reduction by obtaining solutions to problems identified by the teams. The employees' benefits include allowing the individual to make a voluntary impact in his/her work area, receiving recognition for a job well done, and enhancing job satisfaction.

TI employees may also participate in the Method Improvement Recognition (MIR) Program. This program honors employees with certificates of recognition for each MIR implemented, MIR of the quarter awards, luncheons attended by all MIR participants for the quarter at which awards are presented to the originators of top MIR's of the quarter, a 10+ MIR for the year recognition banquet, and a perfect attendance recognition awards luncheon. Most of all, the employees get personal satisfaction from making a contribution to their jobs and being recognized by their peers.

B. Design

DESIGN PRACTICES

The Defense Systems and Electronics Group has a comprehensive set of design standards which have been expanded recently to integrate the company design policy with the templates of DOD 4245.7-M, "Transition from Development to Production." Elements include engineering disciplines, tools and techniques, formal policy statements, lessons learned/experience sharing, training and design automation/tools. The standards flow from a design requirements policy to procedures on technical controls, design to cost, producibility, and quality systems. A design systems manual includes a comprehensive set of concise and very readable design guides covering the following areas:

- Systems Engineering *	- Digital Design
- Analog Circuit Design *	- Testability
- Built in Test *	- Worst Case *
- Power Supply *	- Producibility *
- Mechanical Engineering	- Programming Standards
- ATE and Test Generation	- Software

* - In Preparation

PRODUCIBILITY DESIGN REVIEW

At TI, producibility engineering is a function within manufacturing vis-a-vis design. It is producibility engineering's responsibility to work with both design and production from the proposal point onward to ensure a smooth transition from design to production. Producibility must sign-off all drawings prior to release, but does much more including tool approval, estimating and liaison engineering with parties such as purchasing. Data shows that this group has saved a great deal of time and money through the elimination of problems before they occur on the floor.

The BMP survey team felt that most companies would benefit from such an organization. However, identifying the personnel with the experience needed will be a challenge. Once the experts have been identified, their experience must be captured in a data base before they retire.

C. Manufacturing

MATERIAL HANDLING AND STORAGE

The purpose of material services is to receive, store, distribute and manage all material and inventory. Purchased piece parts are centralized at Lewisville with the primary receiving, incoming inspection and electronics testing facility. The Lewisville plant handles between 50,000 and 70,000 stock requisitions per month.

The TI warehousing function at the Lewisville facility utilizes a four aisle ministacker with 9500 pans. The Sherman plant utilizes a four aisle pallet stacker with 6300 pallets.

This function has obvious advantages. It allows a stores control system to provide detailed location information. A method for reinspection of age controlled, limited shelf life items is included in the warehouse function. Computerized scheduling allows for stock requisitions against detail locations; the result is a very controlled first-in, first-out routine. Also included is prioritization of requisitions by equipment, delivery requirements, work order or manual selection. A detailed tracking of material in incoming inspection is also included.

The computerized system which supports the warehouse function provides data reports such as stock status, shortages, scrap and excess inventory analysis, forecasting, etc. This inventory control database provides part of the backbone of the warehouse function. It is a real time update of stock balances and material status. This automatic updating is based on a high degree of integration.

Since TI has partially used the just-in-time inventory scheme, very rapid, real time warehousing is a must. There are 230 common raw material part numbers delivered to a material accumulation area by three vendors. Material is immediately available to the shop and storage space has been reduced from 16,000 square feet to 5,000 square feet. Packaging material is ordered and delivered directly to the using site. Packaging material was selected for JIT because of its bulk.

ROBOTICS/VISION LABORATORIES

TI has made a strategic commitment towards robotics/vision laboratories. They feel that by committing resources to a laboratory, they can purchase state-of-the-art equipment and debug/develop it in a laboratory setting. This has an additional benefit of developing a technical base within the laboratory staff, rather than relying on the vendors' sales forces and technicians. Each potential automation application is mocked up and verified in these labs prior to full-scale development.

An interesting part of TI's approach to the lab is the fact that they buy state-of-the-art equipment for the lab with the intent of turning the equipment over to the manufacturing organization after the lab has analyzed/evaluated the equipment. They then buy additional new equipment for the lab. This has the beneficial effect of turning over equipment to manufacturing that has already been proven and debugged, while insuring a constant supply of modern equipment for the lab.

PARTS MEASUREMENT SYSTEM

The Parts Measurement System (PMS) incorporates vision systems with computer technology to 100% inspect all dimensional characteristics of the etch circuitry of each microwave circuit board (MCB) layer to insure it is within specified design limits. The system consists of a computer controlled high resolution TV camera, precision remote controlled X-Y table, and a TI computer system and software with input/output capabilities. Operator activities are limited to loading of the MCB layer and input of the designated test program. The system automatically inspects:

- Line width to + 1 mil.
- Hole diameters to + 1-1/2 mil.
- Etch integrity
- Etch alignment
- 100% dimensional verification.

A digital printout of all out of tolerance defects is automatically provided. The average run time for a MCB layer is six minutes, with a 10.6:1 productivity improvement.

PMS was developed under the Navy Manufacturing Technology Program for the MCB operation. The system also is being used for other applications such as inspection of military and non-military connector bodies and integrated circuit lead frames, flat plate antenna parts, microwave circuit module housings, injection molded housings, and 42 different HARM investment castings.

AUTOMATED LASER FOIL ATTACHMENT SYSTEM

TI has developed an automated process using equipment developed with Navy Manufacturing Technology funds to apply foil to microwave circuit board (MCB) assemblies. MCB's require electrical shielding from all radiation frequencies. Thin foils are welded to the layer to prevent signal interferences. A computer driven laser system with an X-Y table is used to weld thin foils to each MCB and ground plane. A fixture holds the MCB and foil during vacuum forming to provide intimate contact which is necessary for laser welding. The process utilizes a "full face" foil to cover the entire MCB surface area. After the foil is attached, the laser is used to trim excess foil from the assembly.

The system is in its final process definition stage. The location of laser spot attachment and laser parameters has proven to be extremely critical to a successful attachment. TI had to develop parameters for true reflow of solder plating on nickel foil. Test data indicates successful attachment. TI is working on final implementation plans of the system.

PRE-SOLDER PWB INSPECTION

An automated inspection process based upon a computer driven machine vision system is being developed to assure correct loading of components onto printed wiring boards prior to wave soldering. The system can verify the following: 1) presence of component, 2) correct component, 3) correct clocking, and 4) correct clinching. Typical inspection time is 45 seconds. This system can collect data to do trend analysis or statistical quality control.

PWB FLOW SOLDER FIXTURES

TI has developed an inexpensive static free fixture that provides good support to PWB boards during the wave solder process. The fixtures are fabricated of a glass-filled phenolic (FM 4002) material in a thermal compression molding process. TI's molds were fabricated at the Sherman, Texas facility at a cost of $6-10K each, depending upon the level of fixture design complexity. The actual fixtures cost approximately $10 each.

Fourteen fixture designs were developed to service 20 different PWB designs. Aluminum rails were added to the fixture edges to provide a mechanical fastening surface for universal pallets. Special molded hold-down clips were also developed for lower-profile and reduced heat retention. These inexpensive plastic fixtures can be used repeatedly (960 times/year) with less than five percent replacement, and .150 inch or less diagonal warpage.

AUTOMATED PRE-SOLDER MASKANT APPLICATION SYSTEM

A temporary water soluble solder maskant is applied to predetermined locations on printed wiring boards prior to the wave soldering using a computer driven material dispensing system manufactured by Knight Tool Company. The maskant is applied accurately and precisely and virtually eliminates operator errors in placement of the maskant. Labor hours in this operation are also reduced.

AUTOMATED LASER SOLDER JOINT INSPECTION SYSTEM (VANZETTI)

Texas Instruments has implemented a Vanzetti laser inspection system which provides a rapid means of inspecting solder joints via comparison of peak thermal unit values to pre-determined upper and lower accept/reject thresholds. These thermal values are obtained by exposing the solder joints to an 8-20 watt laser power pulse for 45 milliseconds, then measuring the heat dissipated from the joint using an IR detector. The system uses a computer to control the movements of the assembly under inspection to the pre-programmed X-Y coordinates of each solder joint, provides statistical analysis of the data obtained, and identifies rejects by component designator and pin number.

The system has not been optimized to the point of total elimination of the need of visual inspection of solder joints. Additionally, it is highly sensitive to variations in both the soldering and cleaning processes. These processes therefore require more extensive control than normally required. The laser system can be used as a process control mechanism.

TI is a recognized leader in this area. Future plans call for continued threshold and tolerance refinements. Statistical control limits will be tightened as additional data is gathered. TI is also working on using the Vanzetti laser inspection system for solder reflow/rework.

COMPOUND APPLICATION ROBOTIC SYSTEM

Microwave circuit boards (MCB) manufacture requires application of four different compounds. These compounds require precise shot size and precise positioning. To automatically dispense epoxy to the required areas on MCBs, TI is developing a Compound Application Robotic System (CARS) under the Navy Manufacturing Technology Program. The system can also be duplicated for other one part or two part compound applications with minor modifications and reprogramming.

CARS is a robotic system (Unimate PUMA 700) that dispenses approximately 0.002 to 0.008 cc of a two part epoxy (Hysol) adhesive to reduce the stress on internal solder joints in HARM microwave circuit boards (MCB's). The CARS system consists of a vision system, precision X-Y table and 6-axis robot. The vision system locates the application areas and adjusts the X-Y table for tolerance buildup. The robot handles the MCB in the cell and holds the epoxy dispensing head during application. The robot changes its own end effectors. The dispensing head is capable of precision application of two-part compounds.

The pre-CARS method required an operator to mix the two part compound in the proper proportions and load it into a manual or pneumatic syringe. The operator had to refer to detailed written instructions while applying the compound to specific areas. The application was tedious, difficult and very subject to operator judgement.

CARS minimizes human operator intervention during operation. The automatic system utilizes robotics and machine vision technologies with user-friendly, menu driven system software. CARS is capable of dispensing other compounds without excessive system design modification.

TEST EQUIPMENT NETWORK

The HARM program is supported by a highly automated system of test equipment that is tied together through a Local Area Network (LAN) system. This system interfaces directly with test consoles and provides a means to automatically store and analyze contractually required data. The burden of performing non-test-measurement related activities, i.e., general computation, is shifted from the test consoles to the central system. The test sets are tied via a star configuration; the clusters are tied to test network computers, which are networked via Ethernet and IEEE 802.3. Benefits include:

- Improved testing throughput due to offline pass/fail computations.
- Automatic loading of test programs from a central, configuration management controlled test set software directory.
- Automatic collection and archiving of test data.
- Summary (yield) data separated from raw, parametric data.
- Summary information is automatically loaded into a Test Event data base.
- Automatic interface with local quality systems
- Analysis capabilities include graphics, statistics, special data bases, and PC data format (i.e., Lotus).

Related projects that use this network include:

- Test set repair tracking.
- Test set availability status.
- Automated material handler for test.
- Expert Systems for test technicians.

MANUFACTURING SCREENING

TI has a very effective system for screening assemblies. Random vibration and thermal cycling are used as suggested in NAVMAT P-9492, the Navy Manufacturing Screening Program.

YIELD ANALYSIS

TI records quality assurance data on a terminal in real-time on the factory floor. This data is utilized to generate standard reports on a weekly and monthly basis. In addition, the quality engineer can call for a report from the database at any time and can sort on any variable such as part number or operation. This lends itself to tracking problems in real-time.

Trend analyses are performed on analog data to predict out-of-tolerance conditions before they occur. Although not an unusual system, it appears to be thorough and as comprehensive as any in use.

FLEXIBLE MANUFACTURING SYSTEM

TI is in the process of installing a Flexible Manufacturing System (FMS) utilizing an artificial intelligence based supervisor at the Trinity Mills Plant. The FMS will consist of four horizontal machining centers plus two robotic deburring stations, a coordinate measuring machine, and a parts washer. An automated guided vehicle will transport fixtured parts (up to 24" long) among the workstations.

The computer system responsible for the FMS scheduling and control will consist of a TI explorer based scheduler which is responsible for overall FMS scheduling. It will be supported by the following:

- Integrated Numerical Programming and Control System (INPACS)
  - An IBM 4361 based DNC system responsible for configuration management of all NC programs
- Terminal Remote Interface Control System (TRICS)
  - Responsible for buffering and downloading N/C programs from IMPAC's to the machine tools

- Distributed Factory Control System (DFCS)
  - A real time control system responsible for automated material handling

ROBOTIC MATERIAL HANDLING SYSTEM

TI's Sherman plant is at the leading edge of machining technology in its approach/commitment to automated machining techniques. The best example of this is the Robotic Material Handling System (RMHS) in place at Sherman. The "factory of the future" is there. The total machine fabrication of given parts is accomplished within an established "cell" of machines that flank a track mounted robot. The parts are delivered to the cell by the Just-In-Time (JIT) delivery concept by using an automatic guided vehicle (AGV). The robot delivers each part from one machine to another by moving along its track when the machining operation is completed at each particular machine. The deburring required on each part is performed at a robotic station. Even the inspection of the machining performed in the cell is done when delivered by the tracked robot to an automated quality control center within the cell. The implementation of RMHS significantly reduces as well as controls material handling on the factory floor.

TRACK MOUNTED ROBOTS

TI makes extensive use of track mounted robots to tend an entire machining cell (up to approximately 110 feet). This is a unique approach, as most other firms tend to rely on AGV'S or conveyors for similar applications.

Conveyor or AGV systems usually require that the part be picked up, either manually or by a robot, and loaded into the machine. Track mounted robots offer an advantage as they don't require any additional equipment/effort for loading and unloading the machines since the part is already in the grasp of the robot. Parts are picked up at the front of the line by the robot, which proceeds to sequence them through a variety of machining, deburring, and gauging operations.

Several different applications of this concept were observed. TI personnel indicated that the systems were accurate and reliable.

JUST-IN-TIME MANUFACTURING

One of the most frequently used/heard "buzz terms" in the discussion of the current U.S. "Industrial Revolution" is Just-In-Time (JIT) manufacturing. The TI Sherman facility has implemented JIT and is realizing positive dividends. Through JIT, TI Sherman has notably increased yields and reduced scrap and rework. JIT also forces a resolution of any part shortages that may occur in the production scheme. Another benefit of JIT is that it forces the vendor to deliver quality parts because the material review board at TI assumes a posture, through JIT, of not accepting defective material on quality waivers. JIT reduces stockpiling of parts as work in process. It improves shop productivity, shop quality, vendor

quality, and customer/vendor relationships because in order to make JIT "work," all parties must communicate and fully comprehend the system.

AUTOMATED INVENTORY CONTROL

Effective inventory control is a necessity for a JIT system of the scale that is implemented at the Sherman Facility. TI is currently in the process of installing a system that will be triggered by a demand signal at the workstation/machining cell. This signal will be automatically transmitted to the Automated Storage and Retrieval System (AS/RS). The AS/RS has a 6300 pallet capacity and is capable of moving 100 loads per hour.

The AS/RS will automatically respond to the demand signal, pull a unit load from storage, update the inventory, and ship it to the work area via an AGV or in some cases via a manually operated tugger cart.

EQUIPMENT SUPPORT AND CONTROL SYSTEM

There are approximately 117,000 pieces of equipment of different types in use throughout Texas Instruments. In order to adequately track the maintenance aspects of this diverse equipment base, a computerized record-keeping system, ESACS (Equipment Support and Control System), was developed and has been in operation since 1978. This system displays the real time status of the equipment to management.

The system produces batch reports automatically providing property accountability, equipment type, usage history, and maintenance information. Equipment specific maintenance data; e.g., description of breakdown, maintenance action, number of occurrences, percent uptime, period time between failures, mean time to repair, cost of labor, and parts and defect codes is available upon request.

The machine history data is then used to compile vendor ratings that are distributed quarterly to machine tool manufacturers and their distributors. These ratings are based on four main criteria: period of time between failure, percent uptime, repair costs (parts and labor) and an age adjustment factor. The machines are categorized into separate groups (verticals, horizontals, lathes, etc.) and then broken out into the specific manufacturer. These ratings are used to evaluate machine performance for future procurement considera- tions. TI also hosts an annual Machine Tool Suppliers' Conference in order to increase communication with machine tool suppliers.

TERMINAL REMOTE INTERFACE CONTROL SYSTEM

TI is in the process of developing an interesting statistical quality control (SQC) tool for its machining equipment. As SQC data is obtained, the data is punched into the Terminal Remote Interface Control System (TRICS) network which controls the direct numeric control operations. The SQC data is then electronically routed to a monitor at the machine where the work is performed. The operator then has the capability of obtaining trend information on the dimensions of every feature that is machined. The system allows the operator several options for analyzing the data (control charts, pareto analysis, etc.). Based on that data, he has the option of modifying or stopping the process.

An additional benefit of the system is that if, for example, one piece out of every eight needs to be inspected, and if eight pieces have already been machined, the operator will be prevented from manufacturing an additional piece, until a piece has been inspected.

IV. PROBLEM AREAS

The problems discussed below were identified by TI as having the potential of being industry wide problems. The BMP survey team will collect more data on these problems from other contractors and government agencies. This data will be reviewed and those manufacturing problems considered to have an industry wide impact will be forwarded to the Electronic Manufacturing Productivity Facility, China Lake, California for research and resolution. Some of the problem areas may lead to the establishment of a government/industry ad hoc group to evaluate the concern and propose alternative solutions.

COMPONENT SOLDERABILITY

Component solderability has been identified as a manufacturing problem by the three companies surveyed and most of the companies scheduled for a future survey. There may be disagreement as to why there is a problem, but the majority agree that pre-tinning is required at the prime contractor level to assure delivery of quality hardware.

TI cited a difference in vendor and prime specifications as a cause for some of the problems. Two examples provided were: MIL-STD-202/method 208 allows 95% wetting while WS 6536 doesn't, and MIL-STD-275 allows PWB defects not allowed for assembly use by WS 6536.

An interim solution to solving the problem at the prime level has been for the prime to 100% pre-tin incoming parts. TI is investigating equipment available to set up an automated pre-tinning process. A system being considered is the one developed and built by General Dynamics Pomona Division, Pomona, California.

CONFIGURATION MANAGEMENT

The Government's inability to receive drawings and data in computer format (digitized data) poses a problem for industry. While industry is encouraged to automate, the Government in general does not accept data packages such as PWB artwork and engineering drawings in a digitized form as "master" drawings. The digitized form is increasingly utilized in production fabrication to drive CAD/CAM Systems. Yet industry is required to create "master" drawings from the digitized form for government review. These "masters" are never used for production purposes.

GOVERNMENT FURNISHED EQUIPMENT

The benefits of JIT manufacturing have been stated earlier in this report and do not need to be restated. However, it was pointed out to the BMP survey team that government furnished equipment (GFE) can have a negative impact on attaining a JIT manufacturing system.

It is obvious that to make JIT work, purchased parts must arrive on a pre-determined schedule that fits into the overall JIT delivery plan. The team observed a problem at the Sherman facility as GFE (in this case, a shipping container) was not available as scheduled. This caused TI to go through the process of temporarily packaging the finished product and then storing it until the shipping containers arrived from the vendor.

A responsive and responsible vendor base is essential to the attainment of JIT. TI feels that if it had the flexibility of purchasing the containers directly, rather than as GFE, it would have had more flexibility and leverage with the vendor. This in turn would make implementation of JIT much easier.

OBSOLETE SPECIFICATIONS

Even with the initiatives implemented over the past six years, industry is still required to produce to obsolete specifications. TI conducted an aging analysis on the first two tiers of MIL-E-5400. The average age of the 1374 specifications and standards in these two tiers is eleven years. Of these specifications and standards, 52.3% of them are over 10 years old, 14% are over 20 years old and 5.6% are over 25 years old.

The new DOD Acquisition Stream Line initiative has an objective to tailor specifications and standards. There is increased emphasis on performance over manufacturing (how-to) specifications. Yet industry is concerned that there is no real interest in specification tailoring. The BMP program team is conducting follow-up on some calls made to the Navy Acquisition Stream Line answering service to assess action being taken and responses provided to the callers.

WS 6536 TRAINING

The new soldering specification requires workmanship training. The Navy has established training sites to train and certify industry personnel to establish company training plans to instruct employees to produce to WS 6536. Because of the large influx of individuals requiring WS 6536 certification, the training sites have a backlog of six months to one year and sometimes longer. This has left industry with many untrained personnel expected to produce to WS 6536.

V. CONCLUSIONS

TI DS&EG has been very successful in developing and implementing automated/computerized systems, equipment and processes. Much of the design, inspection, fabrication, assembly, testing and information systems incorporate the latest state-of-the-art technology. Navy manufacturing technology projects developed by TI have been most successful in providing significant pay backs for the funds invested. Some of these projects which were initiated to satisfy a specific requirement have been tailored and applied to many other applications.

Automation alone does not provide the kind of success TI has realized. Dedication to involving the work force, getting the operators and assemblers involved in identifying and resolving problems and making improvements has been a major contributing factor. TI's effectiveness teams efforts have resulted in improved quality and reliability, and reduced scrap, rework, and overall cost to the Government for the products produced by TI.

The BMP survey team believes that many of the practices identified in this report are indeed best manufacturing practices in the electronics industry. TI is already recognized as a leader in the development of automated laser solder joint inspection. Other areas reviewed by the team appear to be on the leading edge of manufacturing technology. The electronics industry can benefit from some of the practices employed at TI DS&EG.

Most of the manufacturing problems identified by TI have been discussed with other companies as a concern of theirs. TI also identified several new problems. As more surveys and discussions are conducted, all of the problems identified will be reviewed and data will be collected to document the magnitude of the problem. Resolution of these problems may come from another company's efforts (best practice) or from research by a government activity such as the Electronic Manufacturing Productivity Facility in China Lake, California. By forming a collective government/industry position with documentation on issues and problems identified, and establishing a data base of the best practices used in industry, the chances of resolution are increased significantly.